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THE OPENING PRESSURES OF SOME RESPIRATOR VALVES

by

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Corrections to DREO Technical Note 82-11

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Page 4 Para 2 Line 5

Change "open" to "closed"

Page 4 Para 3 Line 3

Change "Vent Din Chamber A is then closed"

to "Vents D and E are then closed"

Page 15 Figure 3

Valve C in Fig 3 is to Air Supply

RESPIRATOR VALVES

by

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ABSTRACT

This paper describes an experiment to measure the opening pressures of two types of outlet valves in use in chemical warfare respirators. Their differences are assessed and a recommendation made concerning their suitability for use in CW respirators.

RÉSUMÉ

Une méthode pour mesurer la pression d'ouverture de soupapes a été appliqué a deux genres de soupapes utilisées sur le masque à gaz. La différence entre ces soupapes concernant leurs fonctionements a été faite a rapport a leur utilisation sur un masque à gaz.

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1. INTRODUCTION

During the mid-1980's the current stocks of C3 nuclear, biological and chemical warfare (NBCW) protective masks will begin to expire. When considering a replacement mask various areas of the C3 requiring improvement must be addressed. These areas relate to the field of vision, the voicemitter and outlet valve assembly, and the faceseal and harness. Consideration is being given to all of these but only the outlet valve will be discussed herein.

Several characteristics of the C3 voicemitter/outlet valve assembly require examination. These are:

(1) The voicemitter tends to amplify the hissing sound of exhaled breath, thereby reducing speech intelligibility; and

(2) When the outlet valve is wetted with condensed moisture from exhaled breath the valve tends to stick in the closed position thus requiring a greater pressure from the lungs to open it. This in turn transforms words like 'had' into 'pad' and further degrades speech intelligibility.

(3) Because of the design of the outlet valve and voicemitter assembly, in which a large annular valve seals on a cone-shaped seat, defects in the assembly line manufacture of the mask can result in the valve not seating properly and producing high leakage rates.

(4) Once assembled, the voicemitter/valve assembly is not designed to be disassembled in the field for cleaning purposes.

Opening pressure may be defined as the force exerted by air pressure that is required to overcome the sum of forces tending to hold the flap against the valve seat. These forces may be the elastic restoring forces of the valve, the surface tension of water between the surfaces, the force resulting from gravity and any other force that tends to hold the valve against the seat.

The opening pressure should be large enough that the valve remains closed when there is no outward flow of air through it but low enough that no excessive increase in pressure builds up in the mask itself, possibly causing a break in the nosecup or peripheral seals. If the opening pressure is too high, the elastic forces of the valve material will cause unacceptably high resistance to the flow of air when the valve is open. The force of gravity can assist in opening or closing the valve depending on the orientation of the valve.

The valve currently used in the C3 mask is illustrated in schematic form in Figure 1. The valve is clamped to the body by means of a washer. The voicemitter body is screwed into the outer body and the valve seats against this to produce a seal. The seating area of the valve is a large annulus of radius 23 millimetres and, if the rubber is in contact over an annular distance of one millimetre, the area of contact is 145 square millimetres.

Figure 2 shows a schematic of a mushroom valve design as used in several types of American mask. This valve has a radius of 13 millimetres, the radius being the distance measured between the center of the valve assembly and the point where the flap meets the valve seat, and for a contact area of one millimetre around the edge of the valve, the contact area is 81 square millimetres. For this type of valve, the annular distance of contact is usually less than one millimetre as the flap seats against a vertical lip whereas for the type of valve used in the C3 mask the contact between the valve flap and the seat is tangential.

2. BACKGROUND

One of the first investigations of opening pressures of valves was carried out by Silverman, Lee and Lee(1) at the Harvard School of Public Health and the Nutrition Laboratory of the Carnegie Institute in Washington. They measured opening pressure by three different methods:

(1) The apparatus consisted of a tee-junction pipe into the base of which compressed air was fed. Just downstream from this inlet was a pinch-type valve for controlling the flow of air into the pipe. At one end of the tee was a bleed valve and at the other, the valve under test. An inclined alcohol manometer was connected to the tube also.

The test valve was fitted to the tee by means of a removable connection, a tube of diameter large enough to enclose the valve, which formed a chamber around the valve. The end of this tube was covered with a soap film and pressure was slowly applied to the valve under test. The pressure at which the soap film began to show displacement was noted and the pressure on the alcohol manometer was recorded. There were two main disadvantages to this system: 1) the soap film was very sensitive to small flows and movements of air and 2), the inclined manometer was not a very accurate means of measurement.

(2) The second method employed was simply an extrapolation procedure. The pressure differential across the valve was measured for various values of air flow. The curve of differential pressure versus air flow was extrapolated to zero flow. Where the curve crossed the axis of zero flow was taken to be the opening pressure. It was felt that this method more closely approximated conditions of actual use as human respiratory action is applied suddenly rather than built up from zero flow.

(3) Thirdly, a method relating simultaneous records of flow and pressure obtained from human subjects was used. Again, extrapolation to zero flow was used to infer the opening pressure.

These three methods were not directly comparable as wet and dry conditions were confused. By wet conditions it was meant that the air used in the experiment was at a temperature of about 37 degrees Celsius and a relative humidity of close to 100%. By dry conditions it was meant that the air temperature was approximately 20 degrees Celsius and the humidity about 50%. Values of 343.2 Pa to 74.6 Pa were found for opening pressures of flutter-type valves when wet. Values as low as 2.0 Pa were found for some valves (the modified Japanese valve). A pressure of one millimetre of water gauge is equal to 9.806 pascals (Pa). Thirty-three different types of valve were tested originating from industrial respirators and gas masks to chemical warfare gas masks.

3. EXPERIMENTAL METHOD

A device was constructed to measure opening pressure and is illustrated in Figure 3. The valve to be tested is

fitted between the two chambers A and B. The seal is effected by seating the valve on a soft silicone rubber gasket in chamber A. Two acrylic tubes, A and B, each sealed at one end, and each approximately one liter in volume, are clamped together to produce the main assembly. An air line from each of the two chambers is connected to a model DP7 variable reluctance pressure transducer marketed by Validyne Ltd. The signal from this transducer is then fed to a digital manometer and a model 713A Hewlett-Packard chart recorder.

Air is fed in at a low flow rate (a few milliliters per minute) to chamber A. The vent D is closed and the bleed device (a needle valve) is adjusted so that the pressure in chamber A rises in a controllable fashion. Vent E in chamber B is left open to the atmosphere. This method of increasing the pressure is necessary to overcome the effects of small leaks around the valve gasket and joints in the walls of the chambers. A differential pressure transducer is connected between chambers A and B and this measured pressure difference is recorded on a chart recorder. In order to test the mushroom-type of valve, which is significantly smaller than the annular -type of valve used in the C3 mask, the valve is placed in an adaptor ring which is mounted between the two chambers.

To make a measurement, the vents in both chambers are opened to the atmosphere to allow the pressure in both chambers to equalize to atmospheric pressure. Vent D in chamber A is then closed, the bleed valve opened, and air allowed to flow in through valve C. The pressure in chamber A rises until the valve begins to open into chamber B, whereupon the differential pressure drops as the absolute pressure in both chambers equalizes. The process is more complicated than this but is discussed in more detail in section 5. The maximum pressure read on the digital manometer is the highest differential pressure reading just before the valves opens.

The apparatus was used to determine the opening pressures of the present valve in use in the C3 mask and various designs of mushroom valves. Valves were tested under both wet and dry conditions, opening horizontally and opening vertically both up and down.

As exhaled breath is almost saturated with water vapor, the wet valve condition corresponds more closely to the conditions encountered in actual use. Wet air was made by passing the incoming air through a water bath kept at a temperature of 37 degrees Celsius. Although some cooling of

the air takes place between the water bath and the valve, a similar cooling takes place between air exhaled from the lungs and the outlet valve in a gas mask under conditions of actual use.

4. RESULTS

The results are shown in tabular form in tables 1 through 4. Each number displayed is an average value of ten readings. An examination of these immediately shows that the C3 valve has a much higher opening pressure, under all conditions, than the mushroom valve. For the C3 valve, the horizontal position of the valve corresponds to the position of the valve in a mask during actual use, whereas for the mushroom valve, the position during use is somewhere between horizontal and down.

For both types of valve in all three positions, the opening pressures under dry conditions were very much less than those under wet conditions. In the case of the C3 valve, values increased by 34% to 41% depending on orientation, the down position showing the greatest increase. The mushroom valves showed similar large percentage changes varying from as little as 6% in the horizontal position to 53% in the up position.

In all cases in the dry environment, the C3 valve had a much higher opening pressure than the mushroom valve; the absolute values in the former ranging from 78.1 Pa to 215.9 Pa and in the latter from 11.7 Pa to 99.5 Pa. In the horizontal, down and up positions, the values for the C3 valve were higher than the mushroom by factors of 3.37, 4.08 and 2.82 respectively. The differences between the horizontal-down and the down-up positions for the C3 valve were not significant. The down-up difference for the mushroom type of valve, however, was significant at the 0.05 level.

In the wet environment, the opening pressures for both valves in all positions were significantly higher than for the corresponding positions in a dry environment. For the C3 valve, absolute pressures ranged from 99.0 Pa to 272.4 Pa and for the mushroom valve from 24.4 Pa to 126.1 Pa. The ratio of opening pressures of wet C3 valves and of wet mushroom valves for the horizontal position yields a factor of 4.25. This factor is 4.54 for the down position and 2.50 for the up position.

5. DISCUSSION

Both types of valve were tested under the variation of two parameters: moisture and aspect. The moisture conditions were wet or dry and the aspect conditions involved the valve opening horizontally, upwards or downwards. The downward-opening position produced the lowest values of opening pressure due to the additional force of gravity assisting the valve to open. For the same reason, the upwards-opening position gave the highest values.

Under wet conditions, an additional force of surface tension between the valve flap and seat contributes towards forces tending to keep the valve closed. The relatively high values for opening pressure for the C3 valve under wet conditions may be explained by the relatively large annular area of contact between the valve flap and seat supplying a substantial surface area of liquid. A similar, though less pronounced, effect was observed with the mushroom valves.

Three of the C3 valves tested showed significantly different opening pressures from the rest of the sample. These were numbered 1, 3 and 7 and have been treated separately in the statistical assessment. This bimodal nature of the distribution may be the result of differences in manufacture of the valve assemblies as the valves tested were taken at random from large samples.

As may seen from Figure 4, the recording trace of the pressure differential across the mushroom valve, at some point after the valve has opened and the pressure begun to equalize, a fluttering is observed as an oscillation in the pressure curve. This may be seen as part of the circumference of the valve opening and closing due to turbulent flow through the orifice which turns to laminar flow allowing a smooth pressure drop. It is tempting to think of valves as 'on/off' switches that open and close at very precisely defined pressures. However, such is not the case. The variations in mass-produced rubber flaps and valve seats combined with moisture and dust at the junction of rubber and metal parts combine to make a reading of opening pressure a quantity difficult to define and measure. Despite that, an estimate of this parameter under different conditions has demonstrated wide variations between two

valve designs. The suitability of any design depends on other factors as well: for example, leakage under static and dynamic conditions, size, complexity of engineering problems in production etc, but the marked difference in the parameter of opening pressure between these two designs points to the mushroom valve being more suitable for an outlet valve in a respirator.

6. CONCLUSIONS

Both valves showed variations according to orientation, the force of gravity requiring a higher pressure in the opening-up case, and both showed variations between wet and dry environments, the wet environment requiring a 30 to 40% increase in pressure, over the dry environment, to open the valve.

The mushroom valve had a significantly lower opening pressure than the annular (C3) valve in both wet and dry environments and in all aspects.

7. RECOMMENDATIONS

Under very cold conditions, the deposition of ice between the valve flap and the seat could be a factor in reducing the opening pressure but, at the same time, increasing the likelihood of leakage. It is recommended that a similar experiment be performed in the temperature range of zero to -40 degrees Celsius.

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TABLE 1

C3 VALVE OPENING PRESSURES (Pa)

DRY CONDITION

Valve number	Orientation		
	Horizontal	Down	Up
1	102.3	90.9	116.9
3	83.7	82.4	88.7
7	82.1	78.1	86.7
Mean	89.4	83.8	97.4
Range	20.2	12.8	30.2
2	189.0	174.0	199.7
4	158.5	148.6	170.7
5	163.2	149.4	182.5
6	172.6	165.4	174.3
8	182.0	178.2	219.5
9	209.5	205.4	215.9
10	174.7	161.0	206.8
11	173.1	166.4	187.4
12	169.2	165.6	199.9
13	171.3	163.2	188.1
Mean	176.31	167.72	194.48
Standard Deviation	14.48	16.15	16.67
Range	51.00	56.80	48.80

TABLE 2

MUSHROOM VALVE OPENING PRESSURES (Pa)

DRY CONDITION

Valve Number	Orientation		
	Horizontal	Down	Up
1	11.9	11.7	12.5
2	48.3	35.7	61.1
3	35.2	23.6	51.9
4	42.6	28.3	54.3
5	61.0	43.6	68.0
6	67.3	68.1	99.5
7	58.1	43.5	80.3
Mean	52.08	40.47	69.18
Standard Deviation	12.14	15.73	18.05
Range	25.80	20.00	47.60

TABLE 3

C3 VALVE OPENING PRESSURES (Pa)

WET CONDITION

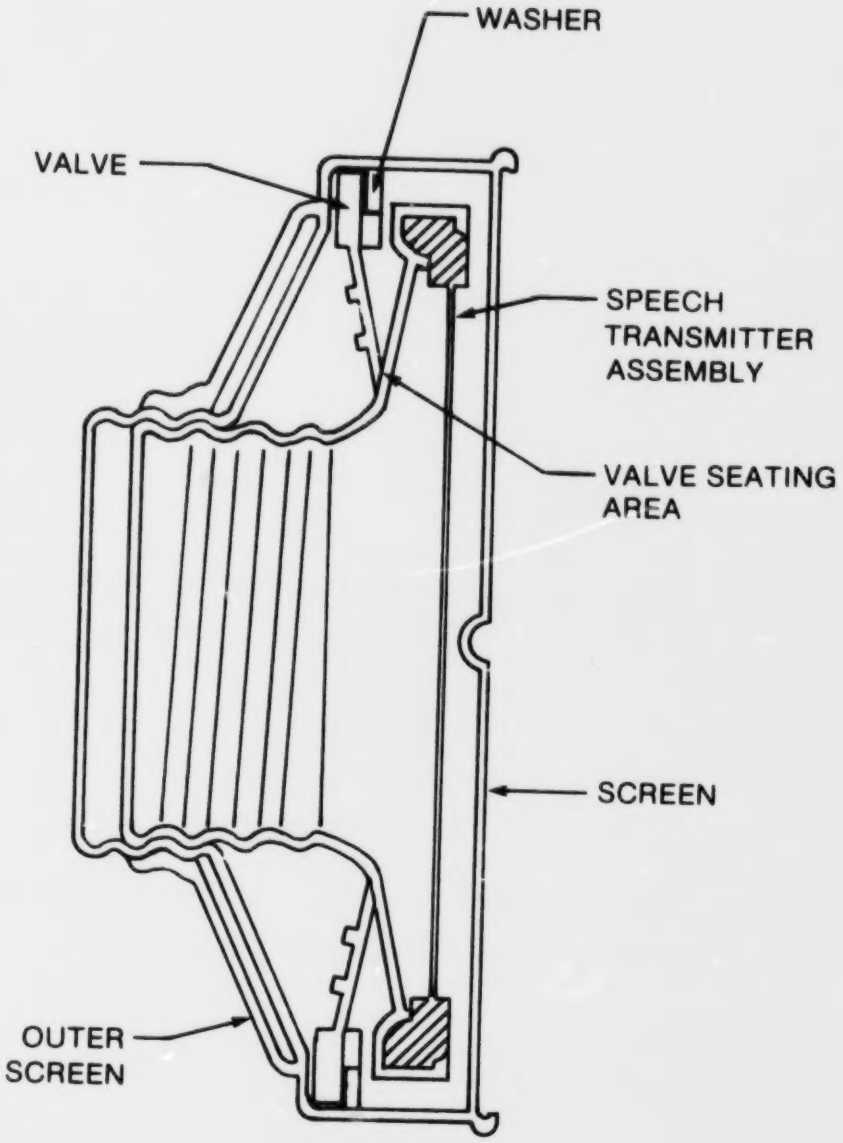
Valve Number	Orientation		
	Horizontal	Down	Up
1	142.6	128.1	202.3
3	136.0	99.0	113.0
7	127.9	205.8	226.3
Mean	135.50	144.30	541.60
Range	14.7	106.8	113.3
2	236.3	263.5	262.3
4	133.9	197.1	234.8
5	260.6	235.8	262.4
6	209.0	190.7	202.8
8	260.5	255.4	255.6
9	243.2	250.8	260.3
10	235.5	252.9	272.4
11	224.2	189.9	258.8
12	262.8	236.0	259.3
13	257.9	213.8	262.4
Mean	232.39	228.59	253.11
Standard Deviation	38.90	28.42	20.07
Range	128.9	65.5	69.6

TABLE 4

MUSHROOM VALVE OPENING PRESSURES (Pa)

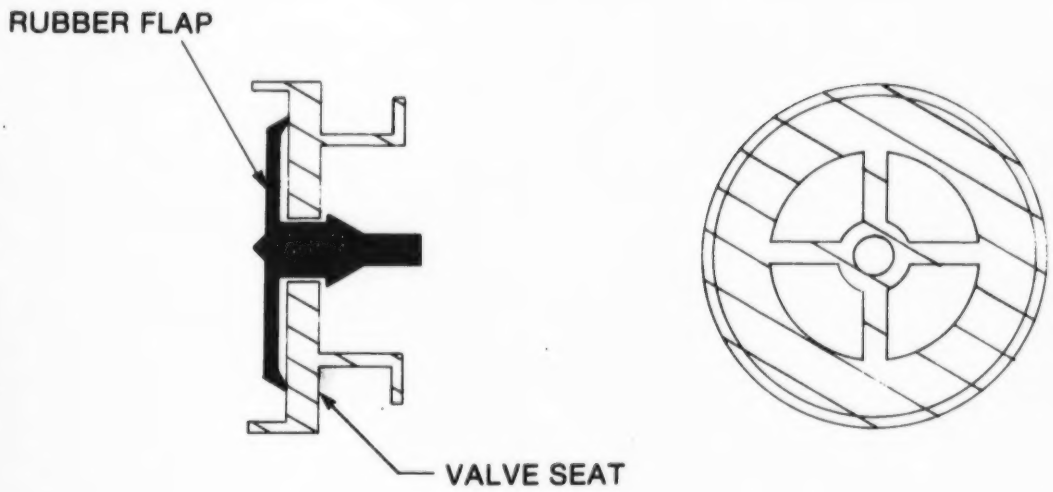
WET CONDITION

Valve Number	Orientation		
	Horizontal	Down	Up
1	32.1	56.0	98.4
2	49.6	33.2	92.5
3	54.8	66.3	96.7
4	65.4	50.8	80.3
5	52.3	24.4	103.6
6	46.9	36.9	126.1
7	44.8	53.9	104.8
Mean	49.41	45.92	100.34
Standard Deviation	10.17	14.78	13.99
Range	33.3	41.9	45.8



SCHEMATIC OF C3 VALVE-ANNULAR CONSTRUCTION

FIGURE 1.



SCHEMATIC OF MUSHROOM VALVE

FIGURE 2.

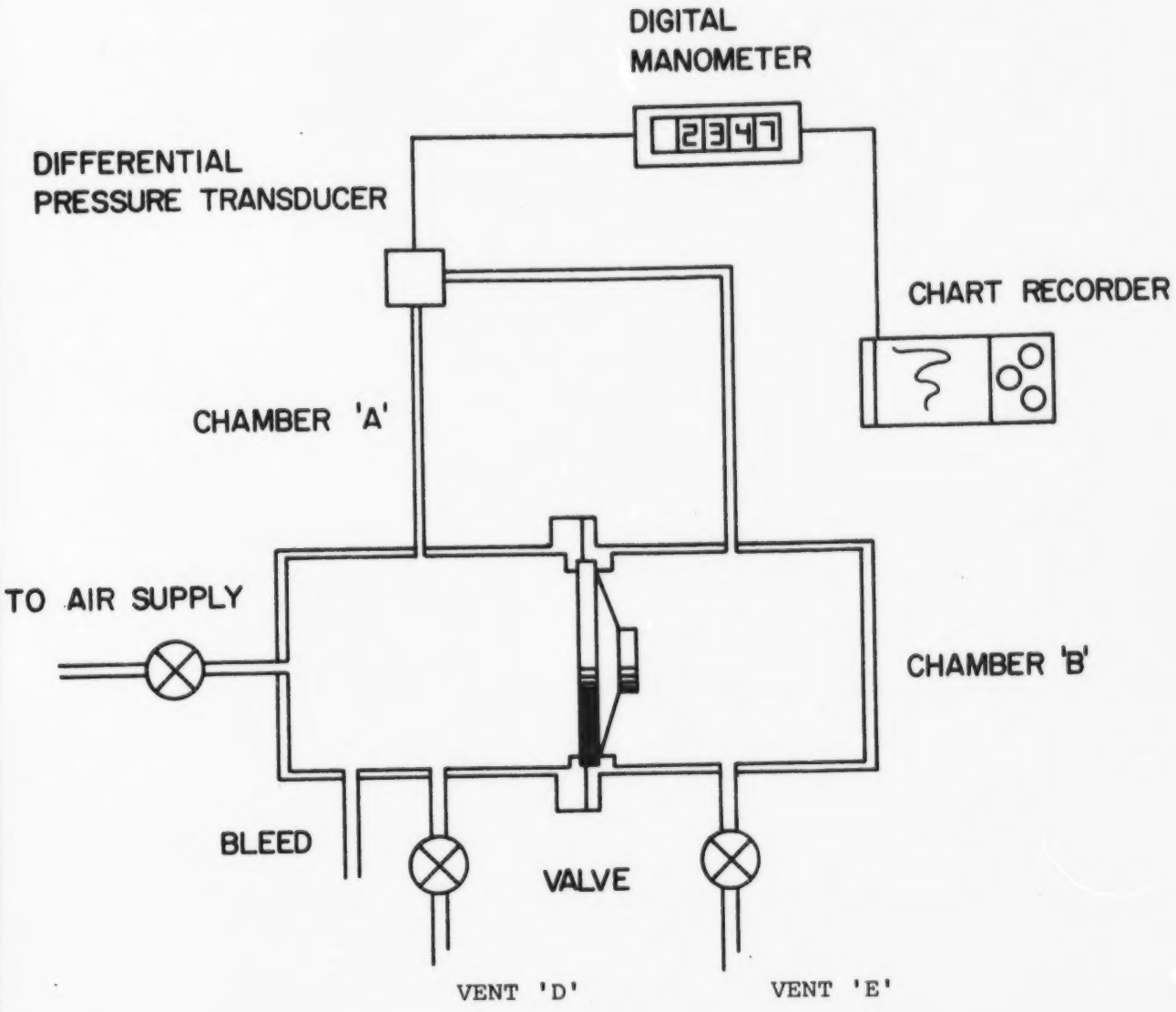
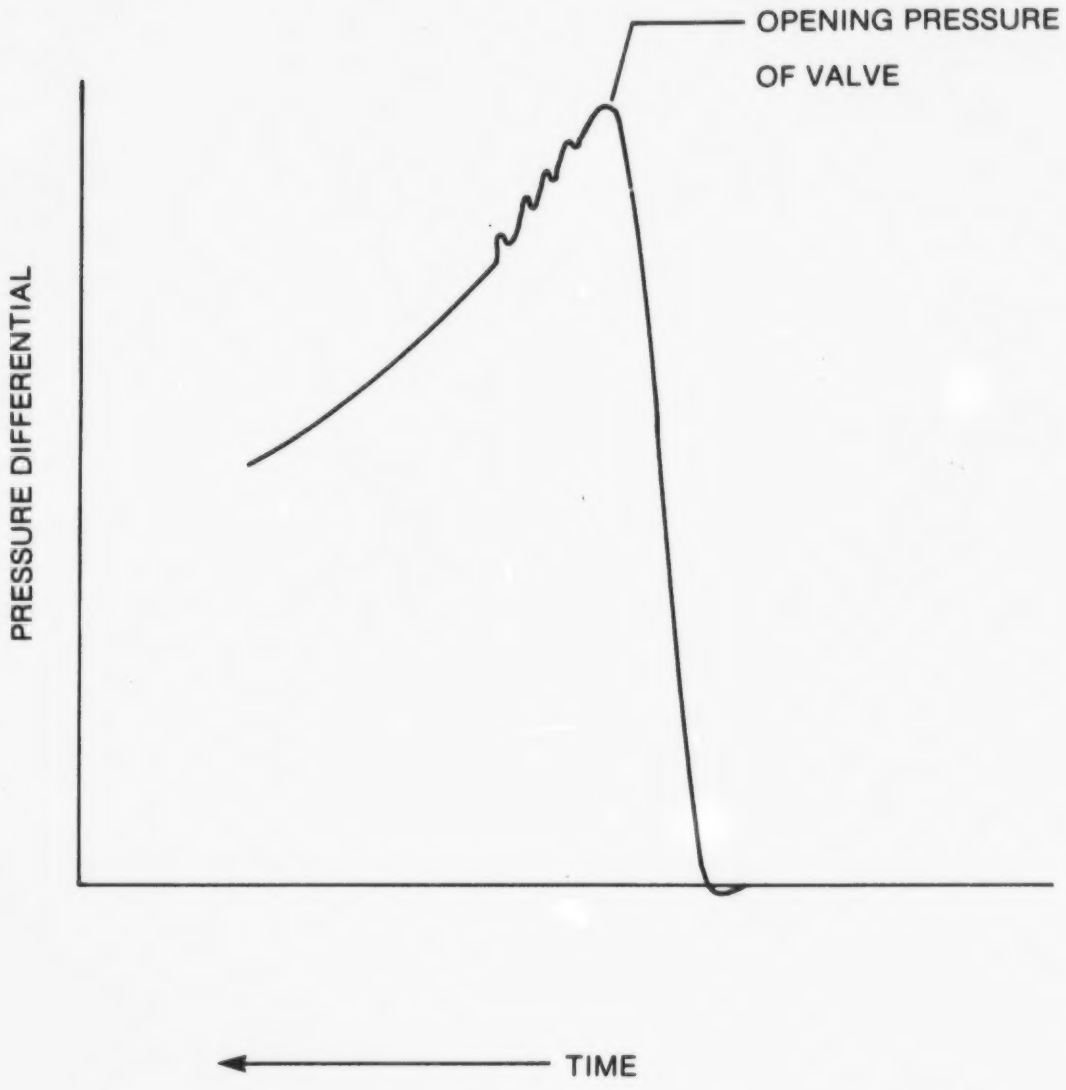


DIAGRAM OF PRESSURE CHAMBER

FIGURE 3.



RECORDING TRACE FROM VALIDYNE PRESSURE TRANSDUCER

FIGURE 4.

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13. ABSTRACT

This paper describes an experiment to measure the opening pressures of two types of outlet valves in use in chemical warfare respirators. Their differences are assessed and recommendations made concerning their suitability for use in CW respirators.

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- protective clothing
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